Impact of New Technological Solutions on Power System Process Information

Review

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Abstract *– The importance of process information in the power system is significant. A wide technological development of microprocessors at the end of the last century led to the introduction of intelligent electronic devices (IED) in the power system. Classical secondary equipment (protection, measurement and control) lacks communication capabilities so it communicates via a remote terminal unit (RTU) with the supervisory control and data acquisition (SCADA) system. Furthermore, an introduction of IEDs with embedded communication has enabled vertical and horizontal multidimensional data exchange between secondary devices. Although a standard-based communication solution solved the primary obstacle to unambiguous data exchange between different secondary equipment. A traditional approach in managing the power system is based on the assumption that each basic function has its own secondary equipment for data acquisition and processing. An introduction of new IEDs has opened the possibility of a new concept of multidimensional data integration and information exchange. This paper shows basic concepts in the creation of a new model of process information.*

Keywords *– data integration, horizontal communication, logical node, IED, process information*

1. INTRODUCTION

An electric power system is a very complex system for real time system management. The importance of process information in the power system is significant due to spatial distribution of electric power plants and substations along with the requirement of a simultaneous time implementation process.

Classical secondary equipment like protection, measurement and control equipment was not equipped with a communication unit. Secondary equipment communicated with the SCADA system via remote terminal units [1].

A wide technological development of microprocessors in the second half of the last century introduced a new kind of secondary equipment. New intelligent electronic devices were introduced in the electric power system. An introduction of IEDs with embedded communication enabled vertical and horizontal data exchange between secondary devices and the SCADA system [2].

A traditional approach to managing the power system was based on the assumption that each basic function, for example measurement, protection and control, has its own secondary equipment for data acquisition and processing [3].

An introduction of modern IEDs and modern standardized communication solutions leads to a change in the existing paradigm of process information modeling. Given this, it is necessary to create a new model of process information which will be based on a new concept of multidimensional data integration and information exchange. The basic concepts for a new model will be presented in this paper.

This paper is organized as follows: Section 2 introduces a brief historical overview of the process information system in the power system, with emphasis on fundamental milestones. Section 3 presents a classical model in process information with its basic elements. Advantages and disadvantages of a model in relation to today's modern power system are presented. Section 4 gives an insight into new opportunities for the exchange of data and information due to new technological developments. The basic concepts for a new model of process information are presented in Section 5. Basic principles are explained and some examples of the applicability of the new process information model are given. A conclusion, which contains guidelines for further development of the proposed model, is given at the end of the paper.

2. A SHORT HISTORY OF POWER SYSTEM PROCESS INFORMATION SYSTEM DEVELOPMENT

The development of process information systems is associated with the development of the SCADA system [4], [5]. To realize such a system it is necessary to have:

- communication infrastructure for data transfer to/from the substation,
- computational infrastructure for processing, storage and presentation of process data,
- devices capable of sending and receiving data and information regarding the state of the observed process.

In order to obtain relevant information about the state of individual devices in the managed process it is necessary to ensure accurate reading of their respective mechanical and electrical parameters. Then, it is necessary to ensure conversion of these values into corresponding sequences of symbols. A computer system and digital communication must be able to recognize these symbols for processing and transmission. This problem was solved by adding an appropriate sensor to primary devices. Through appropriate interfaces these sensors remained connected to appropriate electronic circuitry able to convert their reading into appropriate sequences of bits.

This method of signaling in most cases remained unchanged until the present day. What has changed over the years was the hardware that performs data conversion and data transfer. It increases its accuracy, efficiency and reliability.

In the beginning these were relatively primitive, electromechanical devices, they only had the option of giving visual signals without the possibility of their storage and further processing. Devices that represent this stage are analog ampermeters and voltmeters, push buttons and command switches. System management was handled locally. Automation was performed in a primitive way, through a multitude of cables and relays. Opening or closing of relay contacts was performed by blocking or allowing certain operations.

An introduction of remote terminal units was considered to be the beginning of the implementation of electronic equipment in the SCADA system. Conversion of raw data from the process to digital format was enabled. Primary system devices were merged with appropriate digital and analog input/output units in the remote terminal unit. This enabled the possibility of easy transmission, storage and automatic process of data and management of the installation from a remote center. On the other hand, the basic way of automation systems was not changed (relay logic).

With further development of microprocessor and communication technologies, analog and digital input and output units in the remote terminal unit evolved into an independent hardware unit based on microprocessors designed for a specific function in the substation. These devices have introduced a whole range of new functions and features including auto diagnostics, communication interface, the possibility of storing events chronology, etc. Thereby, they considerably disburden the role of remote terminal units. New devices consolidate the functions of control, measuring, protection and automation thus providing the ability to implement a distributed control system. In this way the management system could be gradually decentralized since each of these devices could have certain autonomy in the decision-making process. This enabled the ability to configure system on functional and spatial distribution. Today, the term intelligent electronic device (IED) represents any device based on microprocessors with the communication unit.

In the last decades, liberalization was a major issue around the world that led to privatization and competition in the area of the electric power sector. Due to the emergence of the electricity market, new entities that operate in this new environment have emerged (e.g. independent production, customer independent supply). New entities in the electric power system demand faster and more accurate information about the state of the system. Therefore, it is important to create a new model of the power system substation process information that will allow easy delivery of necessary information about each element in the system.

Today, the emphasis is placed on communication buses: station bus at the substation level and a new process bus at the process level. To realize this, it is necessary to use IEDs at the process level. Development and testing of such devices is in progress. The realization of such system will simplify the exchange of process data in the substation.

Based on the aforementioned fundamental milestones, a chronological development of the process information system is shown in Fig. 1. A classical process information model is presented in the next section.

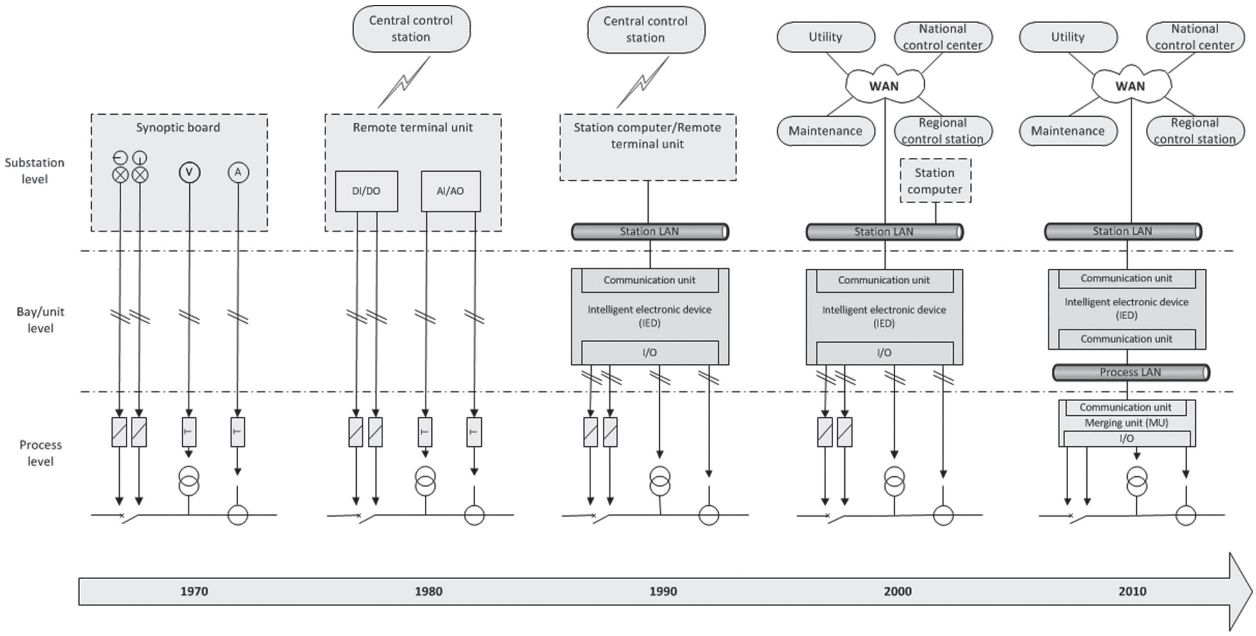

Fig. 1. Timeline of electric power system process information system development

3. A CLASSICAL PROCESS INFORMATION MODEL

Electric power facilities represent a technical system divided into several hierarchical levels. By looking at the substation in terms of analysis or from the standpoint of management, a substation consists of:

- a high-voltage part, which performs the electricity transmission function,
- a low-voltage part, which performs a variety of functions such as the supply power for primary and secondary equipment.

Furthermore, a high voltage and a low voltage part can be divided into individual substation parts. For example, a high-voltage part is further divided according to voltage levels that include:

- 220kV (combines all the elements whose nominal operating voltage is 220kV),
- 110kV (combines all the elements whose nominal operating voltage is 110kV),
- 220/110kV (combines a 220/110kV power transformer and its associated equipment).

Each section represents a separate entity that contains all the elements that belong to the observed voltage level. These subsystems are often referred to as technological units since they represent independent entities. However, this division is still not sufficient for substation monitoring and it represents only a rough substation distribution. To understand substation operation it is necessary to break down the substation into even smaller subsystems. Therefore, each voltage level is divided into several smaller ones - characteristic modules whose behavior is precisely defined. These typical modules are often referred to as technological modules as they represent the elements of technological units. The technological module is the smallest unit and the technological building block for complex technological units.

Specification of all functions in the system allows identification of information management and the exchange of information in the system. Categorization of functions is helpful when considering functions which, as already mentioned, are numerous, and the system requires different performance in certain functions. Information identification is necessary for the process of substation information modeling [6].

A. Technological module

The technological module is the smallest unit and technological building block of complex technological units [7]. Technological modules are considered to be sources and sinks of information. Technological modules are:

- transmission field (TF) (a set of devices connecting the transmission line with the buses and controls the energy flow. This is one of the most common modules in the substation),
- power transformer field (PTF) (a set of devices connecting the power transformer with the bus. Each transformer has two such fields, one for primary and one for secondary side),
- measuring field (MSF) (a set of devices connected to the bus for appropriate measurement),
- merge field (MF) (a set of devices which enables connection or separation of bus systems at the same voltage level),

- power transformer block (PTB) (a power transformer with its respective devices),
- a generator field (GF).

Technological modules present logical units and not specific devices, structures formed in this way are proved to be sufficient for substation monitoring. Observing the operation of individual modules can monitor the work of an individual voltage level and through them the performance of a complete substation. The following figure (Fig. 2) illustrates substation decomposition into smaller subsystems. This is one classic transmission substation. The left-hand side of the figure presents a real power system and the right-hand side presents corresponding technological units and technological modules. Each level consists of already mentioned specific modules where each module performs typical tasks within their technological unit.

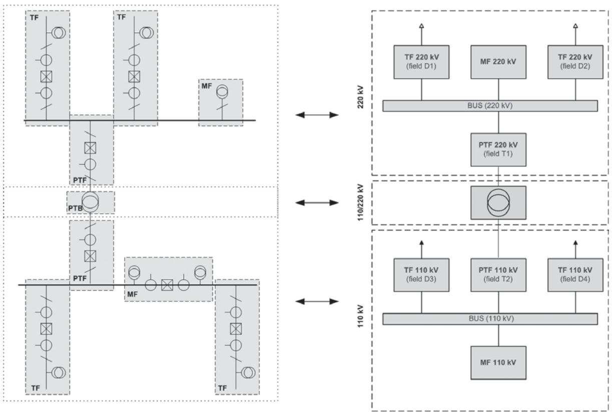

Fig. 2. An example of substation decomposition into technological units and technological modules

B. Functional module

Each of the presented technological modules (TM) is described by a series of information that belongs to different functional modules (FM). A functional module presents a simple function in the substation. In operation, the dynamics of the above information describes the working condition of appropriate technological modules. The following functional modules can be singled out for the substation:

- protection and alert (p),
- group signals (gs),
- switching signals (ss),
- computer equipment signals (cs),
- measurement (m),
- commands (c),
- instructional messages (im).

C. Technological-functional model

A technological-functional model presents the first generation of power system process information modeling. It originated from the early eighties of the twentieth century. It is based on technological models of the substation and information related to its function in the entire substation. Based on the technological-functional model, a database in process information is generated for each substation. An example of a hierarchical connection of technological and functional modules is presented in Fig 3.

Based on the technological and functional modules defined above, a set of processing information of the power system substation can be defined as the sum of certain subsets of information. A subset of information can be formed from technological modules or functional modules.

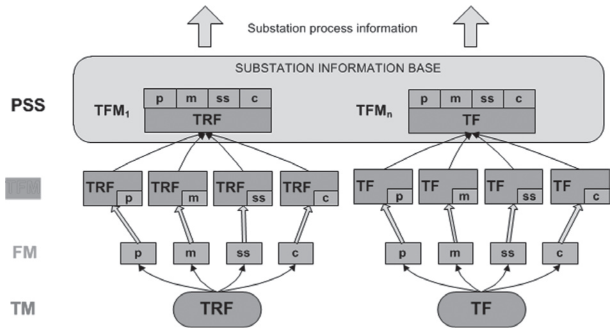

Fig. 3. Structure of the technological-functional model

By introducing the third element of information - value, the information structure from the power system substation can be defined as a three-dimensional vector (Fig. 4). The set of information S at the level of a power system substation [8] for all technological modules and for all types of signals can be defined as:

$$S = \{\alpha_{xyz}\} \qquad \begin{aligned} x &= 1,2,3,...,n \\ y &= 1,2,3,...,n \\ z &= 1,2,3,...,r \end{aligned} \tag{1}$$

where α_{xyz} represents information defined by function x, location y and value z.

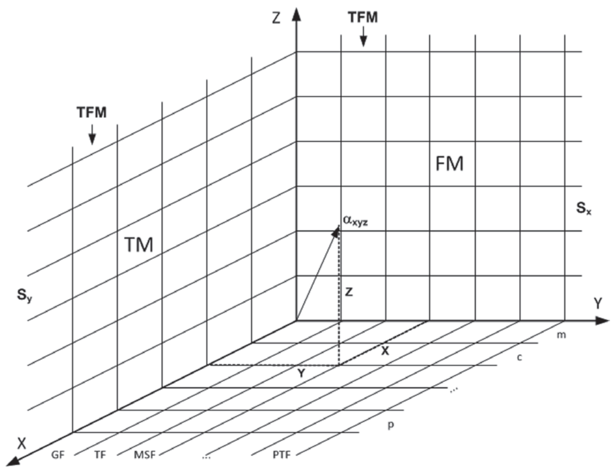

Fig. 4. Information from the power system substation represented as a vector

Subset Sx represents all information of one functional module from all technological modules of a substation, where $x = const$, while the yz-plane relates to this subset. Finally, subset S_{xy} represents all information of one technological module and only one function, where $x = const$ and $y = const$ relate to this subset.

The substation technological-functional model is used for operation analysis and estimation of various information flows. This model has some specific limitation and drawbacks:

- process information are organized at the level of technological modules,
- the entire modeling procedure must be repeated for each substation,
- the device, as a basic element of the substation, is not separated as a carrier of information,
- device states cannot be defined for the needs of modern process information design,
- links among devices cannot be determined,
- redundancy of the data entry is great.

Analysis of dynamic characteristics of a stochastic process information flow was possible by the presented technological-functional model. The model was created during the use of remote terminal units for the purpose of communication. At that time, communication capabilities were limited and therefore it was necessary to conduct the analysis.

In the present circumstances it is necessary to create a new process information model. It is necessary to take into consideration the possibilities of new intelligent electronic devices and possibilities of the modern communication system. The rest of this paper will give emphasis on new technological achievements.

4. NEW POSSIBILITIES FOR DATA AND INFORMATION EXCHANGE

The development of new intelligent electronic devices with an integrated communication unit gave rise to the opportunity for easy data and information exchange. Different IEDs use property communication protocols for data exchange and this is an obstacle for data and information exchange between different IEDs. As a result, there is a need to define a standardized way for data and information exchange. A big step was made by introducing the IEC 61850 standard [9],[10]. The standard defines the semantics of data and principles for data and information exchange. Today, a growing number of intelligent electronic devices support communication based on that standard.

Resolving problems bound to the unique exchange of data and information has opened the possibility for undisturbed communication between individual IEDs. As shown in a historical review, today emesis is on installation of IEDs at all substation levels. This allows simple data exchange, for example between the process level and the substation level. To achieve this, it is necessary to invest in the new infrastructure in order to fully enable unobstructed communication. In this way, communication will be available in two dimensions:

- horizontal, and
- vertical.

Until recently, only vertical communication was available. Initially this communication was between the control center and the remote terminal unit. The development of IEDs enabled communication between the bay level and the substation level.

Horizontal communication is enabled by applying standardized communication solutions. This enables interaction between IEDs at the same level. Thereby it is possible to connect more devices in more complex structures to achieve more complex automated functions. Further development of process level IEDs will enable their integration into complex functions.

Complex functions represent a substation automation system (SAS) (Fig 5). SAS is one of the most important parts of modern facilities. From a logical point of view, the substation automation system is a set of functions that interact with each other and perform a comprehensive job of substation management. The logical structure of the substation automation system represents functions and data distributed within the physical structure [11]. SAS functions can be divided into three levels:

- station level functions,
- bay/unit level functions,
- process level functions.

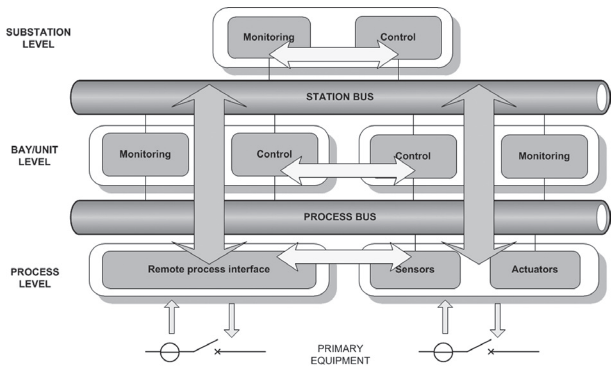

Fig. 5. SAS structure with data and information exchange

These three levels are associated with logical interfaces that define data exchange between different levels and within the same level. Logical interfaces serve to define two important local area networks or bus systems in the substation:

- station bus,
- process bus.

Station bus connects the station level with the bay level and different IEDs within the bay level. It provides monitoring and control data exchange between the bay and station level. It also enables data exchange within the bay level and the within station level.

Process bus connects the bay level and the process level and different IEDs within the process level [12]. It provides instrument transformers data exchange and control data exchange between the process and the bay level.

Due to the change in communication possibilities and application of IEDs there is a need to create a new process information model.

5. NEW PROCESS INFORMATION MODEL

Information exchange basically relies and depends on a well-defined information model. The introduction of a new standard provides the use of approach that models common information that can be found within the real device. With this modeling method a picture of an analog world is created for a substation automation system. Information access and exchange is conducted in such manner that it is independent of specific implementation. This is achieved by using an abstract model. The abstract model is a model in which real objects, processes or situations are not presented by physical assets, but are represented by symbols. The concept of visualization (Fig. 6) provides a view in real device properties (information) that are of interest in exchanging information with other secondary devices [13]. An approach is based on decomposition of substation functions into the least possible entities that are used to exchange information. Granularity is achieved by a reasonable distribution of these entities in dedicated devices or IEDs.

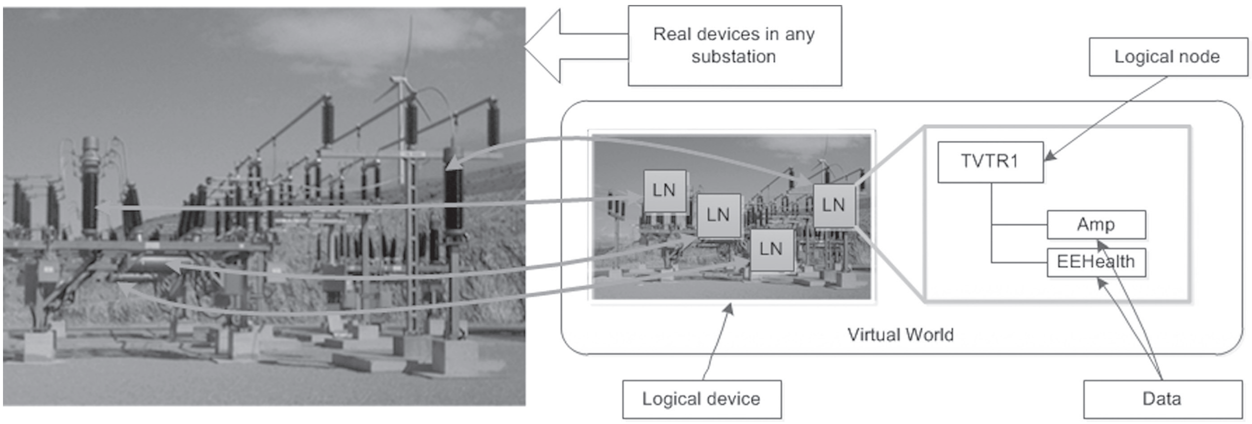

Fig. 6. Virtualization concept

Due to new changes in technology of data and information exchange it is necessary to introduce new concepts such as logical node (LN), logical device (LD), physical device (FD), physical and logical connections. A new model of process information will be created based on these new concepts.

A. Fundamental building unit of the model

The basic building block for the new model is a logical node. It represents a model of a real device or simple function of a real device. A logical node presents a container of information. Information is presented by using data objects and data attributes. Logical nodes contain a few up to 30 data objects and the data objects may contain from a few to 20 attributes of data [14]. Therefore, a logical node can contain more than 100 individual types of information organized in a hierarchical structure (Fig. 7).

Logical nodes can be classified according to the levels at which they are located in the substation. They can be distributed by the levels of the substation automation system. Thr first letter of the logical node indicates the group the node belongs to (C – control, M – measurement, X – switching equipment, T – instrument transformers, P – protection, etc.). Based on these basic building blocks, it is possible to generate complex functionality.

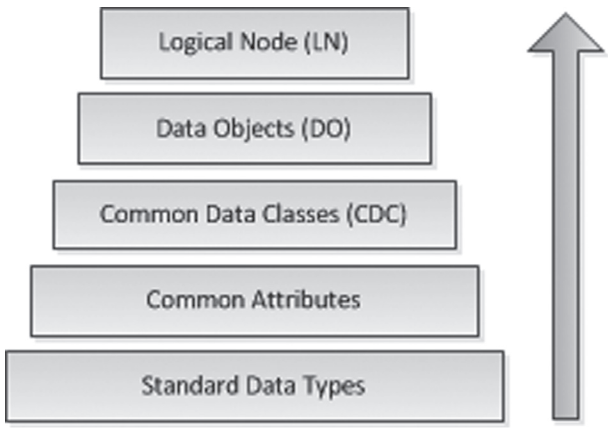

Fig. 7. Information model hierarchy

B. Creation of complex functions

Intelligent electronic devices in this model are presented as physical devices. The logical node is part of a physical device and it includes specific functionality of the device and contains a particular set of information.

The substation automation system consists of a number of IEDs connected to a communication network. IEDs are connected with physical connections (PC). Logical nodes are connected by establishing logical connections (LC).

The function is a combination of connected logical nodes and it is called a logical device. Creating a function of connecting nodes is a very complex task (Fig. 8).

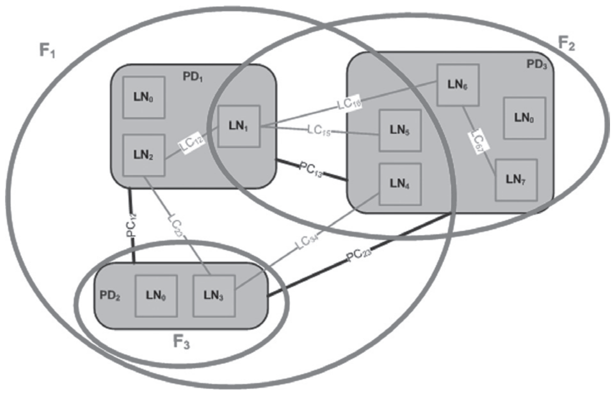

Fig. 8. Creation of complex functions

Grouping of logical nodes that together perform a task creates a function. The following equation shows that:

$$f_n = \sum_{i=1}^{m} (LN)_i \qquad m \in 1, 2, ..., k \qquad n \in 1, 2, ..., k \tag{1}$$

where f is a function of the substation which can be l. Functions are created by logical nodes LN, which can have a maximum of k logical nodes in each function.

A new process information model is based on function decomposition in the substation automation system and on the concept of the logical node. This provides new opportunities for data and information exchange. In the following subsection, a process information flow based on a new concept will be shown.

C. Process information flow

Creation of a new information model enabled a multidimensional insight into process information. For example, process information can be viewed from the standpoint of substation levels (substation level, bay/unit level, process level) or from the standpoint of logical nodes and their data objects and data attributes. The next example will illustrate possibilities of connecting logical nodes in complex substation automation functions (Fig. 9) and display data and information exchange between logical nodes.

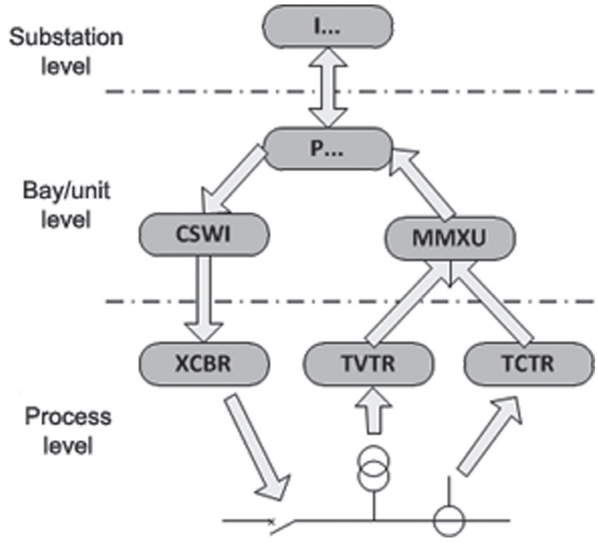

Fig. 9. Process information flow between logical nodes

Logical nodes at the process level represent data from primary equipment. Circuit breaker, current and voltage instrument transformer are used in this example. Measurements are obtained by instrument transformers that are in information sense represented by logical nodes TVTR and TCTR.

Logical nodes at the bay/unit level represent basic functionality of individual devices. In the above example, a protection IED is used. A protection IED is presented by logical nodes MMXU, CSWI and a P group logical node. Logical nodes do not have to reside in one IED. Instrument transformers sampled data are processed at this level and information on the measurements are now located in the logical node MMXU. This information is then sent to a logical node associated with protection. If the observed value exceeds the threshold, command to act will be sent to circuit breaker. The logical node CSWI represents a control device for the circuit breaker. Information about the state of the circuit breaker can be obtained from the logical node XCBR.

Logical nodes at the station level serve as interfaces for connection with other substations or remote control stations.

Function decomposition using basic logical nodes and their interaction (data and information exchange) is represented in this example. Any complex function in the substation automation system can be presented by a similar example.

All basic concepts that should be taken into consideration for creation of a new model of process information are presented. The emphasis is put on process information exchange and unification of process information.

6. CONCLUSION

The impact of new technological solutions in process information is important. Constant progress in technology, along with emerging conditions in the electric power sector resulted in the creation of a new model of process information for the substation. Introduction of the current substation process information model was necessary to understand the methodology for process information modeling.

The development of communication technology enables multidimensional data and information exchange. Sharing of data and information can be achieved in the horizontal and vertical direction. Due to the change, there is a need to define new concepts such as a logical node and a logical device. A logical node is a basic information unit. A logical device is a combination of logical nodes representing complex functionality.

The new IEDs provide a variety of information only loosely associated with monitoring and control. The new model can be applied to all new entities in the power system. A new process information model allows easy creation of complex functionality in the substation automation system. This provides an opportunity for creation of complex distributed algorithms for the purposes of substation management.

Further work will be carried out for testing the dynamic characteristic of process information based on this new model for some distinctive substations. Testing will be conducted to obtain qualitative and quantitative analysis of the process information model with observations of vertical and horizontal communication in the substation. Tests will give an insight into the behavior of the process information system in characteristic emergency situations.

ACKNOWLEDGEMENT

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